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Spray Charging and Trapping Scrubber for Fugitive Particle Emission Control

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16. ABSTRACT The paper gives results of theoretical and experimental evaluations of the control of fugitive process emissions (FPE) with a Spray Charging and Trapping (SCAT) scrubber. Theoretical calculations showed that collection is better than 90% for all particle sizes. The SCAT uses an air curtain or jets to contain, convey, and divert the FPE into a charged spray scrubber. Experiments were performed on an 8000-cfm bench scale spray scrubber to verify the theory and feasibility of collecting fugitive particles with charged water spray. The results of the experiments and the comparison between theory and data are presented. The air curtain, developed for conveying the FPE to the spray scrubber, for collecting the crosswind, and containing hot buoyant plume, can achieve a smaller expansion angle and a lower entrainment rate than those reported in the literature. The design and air flow field for the air curtain are presented. The air curtain successfully deflected crosswind up to 15 mph and containing hot buoyant plume. At an air curtain/spray scrubber separation of 3 m, an air curtain with slot width of 5.1 cm and air exit velocity of 20 m/s can contain a hot plume rising at a velocity of 200 cm/s and has a temperature of 470 C.

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Scrubbers	Air Curtains	Stationary Sources	07A,13I	13M
Leakage		SCAT Scrubber	14G	
Industrial Processes		Fugitive Emissions	13H	
Spraying		Spray Charging		
Dust		Particulate	11G	

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Spray Charging and Trapping Scrubber for Fugitive Particle Emission Control

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The control of fugitive process emissions (FPE) with Spray Charging and Trapping (SCAT) scrubber was evaluated both theoretically and experimentally. The SCAT uses air curtain and/or jets to contain, convey, and divert the FPE into a charged spray scrubber.

Experiments were performed on an 8000 cfm bench-scale spray scrubber to verify the theory and feasibility of collecting fugitive particles with charged water spray. The effects of charge levels on drops and particles, nozzle type, drop size, gas velocity, and liquid/gas ratio on collection efficiency were determined experimentally. The results of the experiments and the comparison between theory and data are presented.

An air curtain was developed for conveying the FPE to the spray scrubber, deflecting the crosswind, and containing hot buoyant plume. The design and air flow field for the air curtain are presented.

The spray charging and trapping (SCAT) scrubber system represents a simple and inexpensive method for controlling fugitive particle emissions (FPE). The SCAT system uses air curtains or air jets to contain, divert, and convey FPE into a charged spray scrubber located near the source.

The SCAT system has two sections arranged in a push-pull configuration with the fugitive particle emission source situated in between. The fugitive particles are contained with air curtains and are pushed away from the source into the spray scrubber. The scrubber has a low pressure drop entrainment separator to remove the spray drops.

The water from the entrainment separator can be passed through a separation process, such as a filter, to remove the collected dust particles. The water may then be recycled and the dust may be disposed of in such a way as to prevent its redispersion. Alternatively, a blow-down stream of dirty liquid may be directed to a disposal system.

The major SCAT feature which suits it to FPE control is the use of air curtains and/or air push jets. The use of air curtains minimizes the requirement for solid boundaries and enables access to the source. Air curtains could also be used to deflect the wind to minimize the dispersion and the volume of air to be cleaned or to deflect a buoyant plume from a hot source. For example, the Naoshima Smelter of Mitsubishi Metal Corporation of Naoshima Island uses an air curtain to control the fugitive emissions from a copper converter.[1] In that system, fumes from the converter are entrained in the air curtain and then ducted to a central particle control device. The SCAT design is very compact and portable. No duct work or hooding is required and scrubber size and water consumption are kept to a minimum.

In practice the SCAT system design will depend on the specific site. However, general design information on the air curtain and the spray scrubber could be obtained in separate bench scale studies. The results of these studies are presented here.

Nomenclature

d_d = drop diameter, cm
f_A = fraction of duct area covered by drop, fraction
K_p = inertial impaction parameter, dimensionless
Pt_d = penetration for particle diameter, d_p, fraction
Q_G = volumetric gas flow rate, m^3/s
Q_{Gj} = volumetric gas flow rate at nozzle exit, m^3/s
Q_{Gx} = average gas flow rate at x meters downstream from nozzle, m^3/s
Q_L = liquid volumetric flow rate, m^3/s
R_d = distance travelled by drop relative to gas, m
u_{Gc} = centerline gas velocity, m/s
u_{Gj} = gas velocity at nozzle exit, m/s
u_{Gx} = average jet velocity at x meters downstream from nozzle, m/s
w = slot width, m
x = coordinate relative to gas, m

Greek

η = single collector collection efficiency, fraction
$\bar{\eta}$ = average particle collection efficiency over drop range, fraction

Air Curtain Study

An air curtain is a sheet of air blown either by a jet or out of a slot at high speed. Air curtains have been widely used in industrial and commercial plants, mainly to provide constant access or to isolate a warm interior from the cold outdoors or vice versa.

Most of the published information on air curtain performance and design has been related to air conditioning and ventilation. There is little published literature on dust containment even though it has been used for this purpose in

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industry. Only one report[2] has been published on the application of air curtain to block or deflect crosswinds.

The design of the SCAT system requires information on several parameters of the air curtain jet stream. The most important parameters are the jet expansion angle, air entrainment ratio, mixing of particles in the curtain, effect of crosswind, and the effect of hot sources. The jet expansion angle and particle mixing determine the overall cross-sectional dimensions of the spray scrubber or the receiving hood. The air entrainment ratio determines the volumetric flow rate. The crosswind and heat effect dictate the placement of air curtains and sprays.

In the SCAT system, the air curtain should have a small expansion angle, small air entrainment ratio, and a uniform velocity distribution. It is generally known that for uniform velocity distribution, the distribution manifold or duct should have a constant static pressure from end to end. To obtain constant static pressure, the manifold should have either a very large cross-sectional area compared to the total nozzle area or a decreasing cross-sectional area to keep the velocity head in the manifold constant.

The air jet nozzle was a continuous slot 2.1 m (7 ft) long. The slot was formed by two parallel plates which protrude 22.9 cm (9 in.) from one side of the duct. The distance between the plates, which is the slot width, could be adjusted. The slot was divided by thin cross-plates at 5.1 cm (2 in.) apart, so that the air would discharge perpendicularly to the longitudinal axis of the duct.

The air curtain flow field was measured for several slot widths and air slot exit velocities. Velocity profile was measured with the slot oriented vertically. Linear velocity was measured with a constant temperature thermal anemometer for three vertical levels at several downstream locations from the slot. The results were compared with the equations derived for a two-dimensional jet exhausting into still surroundings and jets with two-sided expansion. The equations for centerline axial velocity decay and air entrainment ratio are:

$$\frac{u_{Gx}}{u_{Gj}} = 2.45\left(\frac{x}{w}\right)^{-0.5}, \frac{x}{w} > 6 \qquad (1)$$

$$\frac{Q_{Gx}}{Q_{Gj}} = \frac{u_{Gj}}{u_{Gx}} = k\left(\frac{x}{w}\right)^{0.5} \qquad (2)$$

These equations can be applied up to a distance of about 6 slot lengths. McElroy[3] suggested a value of 1.02 for the constant, k, in Eq. (2). Abramovich[4] calculated the constant to be 0.53 and it is 0.78 derived from Prandtl eddy viscosity model.

Figures 1 and 2 show the measured centerline axial velocity decay and entrainment ratio, respectively. The agreement between the measured and predicted centerline velocity decay is good. The measured entrainment ratio was much lower than that calculated from Eq. (2) with the value of the constant suggested by McElroy. The measurements lie between the predictions by Abramovich and present study and are equal to the average of the two predictions.

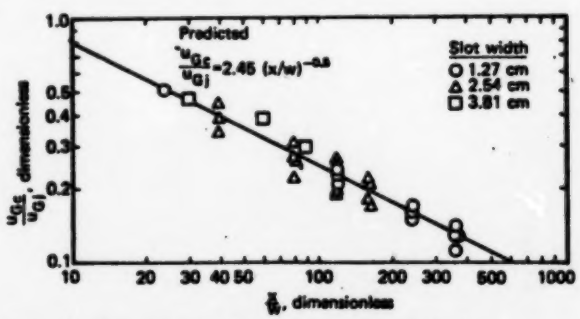

Figure 1. Measured and predicted centerline axial velocity decay.

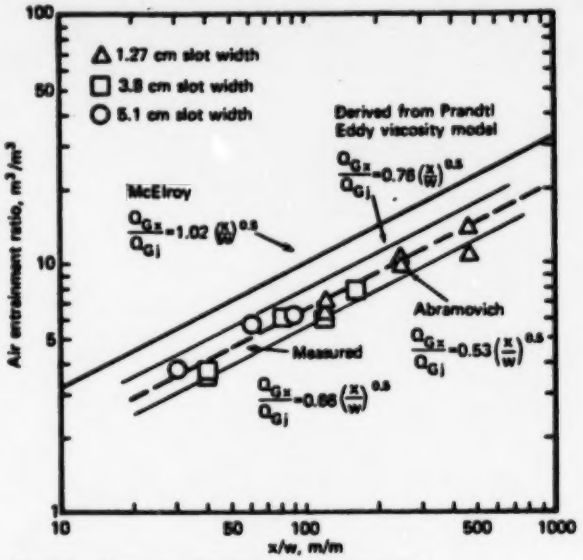

Figure 2. Measured and predicted air entrainment ratio.

The measured jet expansion angle varied between 20° and 28°, depending on air exit velocity. The average of measured jet expansion angles agree with that calculated by Abramovich of 25°. However, it is smaller than that reported by Tuve and Priester[5] of 32° to 34° and that suggested by Hemeon[6] of 30° to 40°.

Charged Spray Scrubber Study

Theory

For a spray system, collection by drops is the principal collection mechanism and the particle penetration for a given size particle is given by Calvert[7] in the following expression:

$$Pt_d = \exp\left[-\frac{3Q_L}{2Q_G d_d}\bar{\eta}\right] = \exp\left[-\frac{3Q_L}{2Q_G d_d}\int_0^{R_d}\eta f_A dx\right] \qquad (3)$$

"η" is the instantaneous single drop collection efficiency and can be obtained by solving the equations of motion. Walton and Woolcock[8] performed experiments to measure the efficiency of neutral drops collecting uncharged particles. Calvert[9] approximated their data by the following equation:

$$\eta = \left(\frac{K_p}{K_p + 0.7}\right)^2 \qquad (4)$$

There is no explicit expression for "η" when electrostatic, inertial, and viscous forces are simultaneously present. Others[10-12] have solved the equations of motion numerically on a digital computer for the collection of fine particles by a single spherical collector and presented their results in graphical forms.

Experiment

Charged spray scrubbers have been studied experimentally by Lear[13,14] and Pilat.[15-18] However, their data are not suitable for verifying Eq. (3). Bench scale experiments were performed to determine the minimum water requirements, to aid the selection of spray nozzles, to study various drop charging methods, to determine the effect of drop and/or particle charging on particle collection efficiency, and to verify published theories.

Figure 3 shows a sketch of the charged spray experimental setup. The scrubber was made of thin aluminum sheets and supported on PVC frames in order to permit electrical current measurements. The cross section of the scrubber was 0.91 m × 0.91 m (3 ft × 3 ft). The overall length, including the blower was about 11 m (36 ft). The scrubber system consisted of a flow straightening section, an inlet particle sampling section, a particle charging section, a spray section, an entrainment separator, and an outlet sampling section.

The particle charger section consisted of two rows of corona wires. Wire diameter was 0.18 mm (0.007 in.). The spacing between wires within the same row was 6.5 cm (2.5 in.). The ground electrodes were 1.3 cm (0.5 in.) diameter aluminum tubing.

The overall length of the spray section was 2.44 m (8 ft) including two spray banks. The water was charged by induction. The nozzles and water feed lines were kept at ground potential. A high voltage grid assembly was placed in front of the nozzles to charge the water drops. This arrangement not only simplified the construction by eliminating a complicated electrical isolation system but also gave a high charge level on drops.

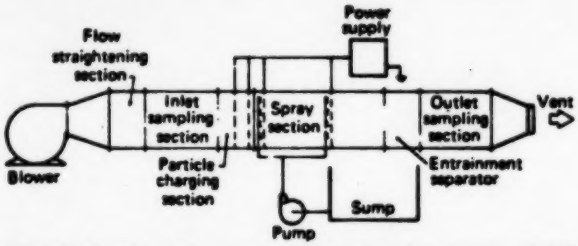

Figure 3. Experimental apparatus for studying charged spray section of SCAT scrubber.

Drop charge was measured by placing a drop collector in the scrubber. The collector collects the drops and their charges which are measured by leaking the charge to the ground through an electrometer. Thus, by monitoring the current and sampling time, and measuring the amount of water collected, the charge level can be calculated.

Figure 4 shows the measured charge level on drops. Nozzles were hook type hollow cone nozzles and the spacing between the grid plane and the nozzle plane was 1.3 cm (0.5 in.). Curve "A" is for a water flow rate of 9.5×10^{-4} m³/s (0.3 gpm/nozzle) and a pressure of 450 kPa (50 psig). Curve "B" is for water flow rate of 7.2×10^{-4} m³/s (0.25 gpm/nozzle) and a pressure of 380 kPa (40 psig). The drop diameter, which was measured and sized with a photographic technique was about 240 μm.

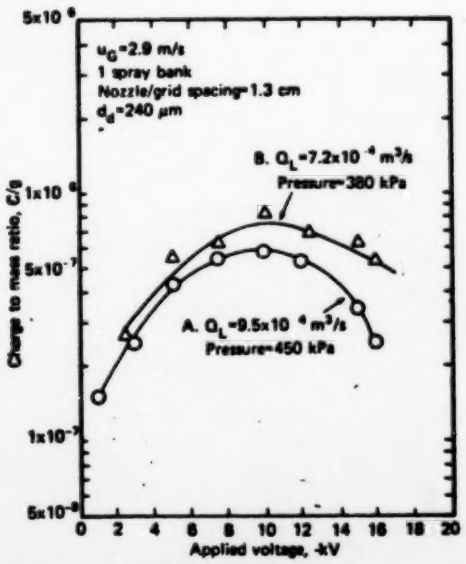

Figure 4. Measured charge level on drops.

The measured drop charge is in good agreement with that reported by Pilat.[15]

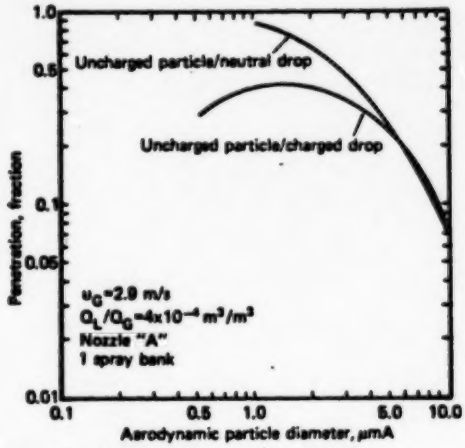

Figure 5. Measured spray scrubber penetration.

Data

The particle collection efficiency of the charged spray scrubber was determined by simultaneously measuring the particle size distribution and mass concentration at the inlet and outlet of the scrubber.

The scrubber was operated for four conditions:

1. Uncharged particles/neutral drops,
2. Charged particles/neutral drops,
3. Uncharged particles/charged drops, and
4. Charged particles/charged drops.

Figures 5 and 6 show the data for nozzles "A" and "B", respectively. The measured mass median drop diameter, spray angle, and discharge coefficient for nozzle "A" (hook type) were 240 μm, 100°, and 0.63, respectively. They were 350 μm, 87°, and 0.69, respectively, for nozzle "B" (pigtail type). Only one spray bank was used in all experiments and nozzle pressure was maintained at 432 kPa (48 psig). One power supply was used to charge both the particles and the drops. The applied voltage was −10 kVDC. The measured charge/mass ratio was -1.5×10^{-5} C/g for particles with a mass median diameter of 3 μmA and a geometric standard deviation of 2.5.

As can be seen from Figures 5 and 6 the collection efficiency of the spray scrubber improves by charging either the water or the particles. Further improvement was measured when the water and particles were oppositely charged. The improvement is more with submicron particles. For particles with diameters larger than 5 μmA, charging the water and/or particles, has little effect on efficiency.

The scrubber with nozzle "A" has better collection efficiency at a lower liquid/gas ratio than that with nozzle "B". A possible explanation is that nozzle "A" produced finer drops.

Comparison between Data and Theory

Eq. (3) along with the drop trajectory formula given in Walton and Woolcock[8] by Giffen and Murozew and the ap-

propriate single drop collection efficiency were used to predict the spray scrubber performance. Figure 7 shows the predicted and the measured grade penetration for the uncharged particle/neutral drop condition. As can be seen, the agreement is good.

For the electrostatically augmented conditions, Nielsen's graph for single drop collection efficiency was used in the calculation. The predictions were identical to those for the uncharged condition. This means we expect no improvement in efficiency with electrostatic augmentation. This is contrary to experimental findings. The discrepancy could be due to the assumption that drops were of uniform size and carried the same amount of charge. In the present study, drops were charged by induction. It is well known that not all drops, especially those in the middle of the spray cone, can be charged by this method.

Conclusions

A simple technique for controlling fugitive emissions has been developed. The technique involves the use of air curtains and air jets to contain and convey the emissions into a nearby spray scrubber.

The collection efficiency of a spray scrubber was investigated experimentally. The collection efficiency could be improved by charging the water and/or the particles. The measured particle penetration agrees with theoretical predictions. For the electrostatically augmented scrubber, the measured penetration is lower than that predicted.

Air curtains have been used in industry to contain dust but no carefully performed study has been reported in the literature. The air curtain developed in the present study can achieve a smaller expansion angle and a lower entrainment ratio than those reported in the literature. Small expansion angles and entrainment ratios are beneficial to the control of fugitive process emissions with the SCAT system.

A prototype SCAT has been built by A.P.T. to study the effects of crosswind, hot buoyant plume, and containment efficiency. Available data revealed that the air curtain was successful in deflecting crosswind up to 15 mph and containing a hot buoyant plume. At an air curtain/spray scrubber separation of 3 m, an air curtain with slot width of 5.1 cm and air exit velocity of 20 m/s can contain a hot plume which is rising at a velocity of 200 cm/s and has a temperature of 470°C.

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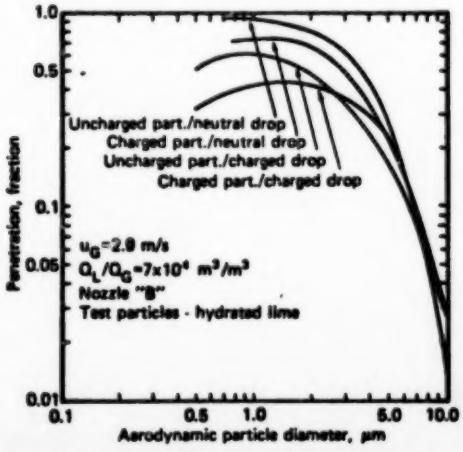

Figure 6. Measured SCAT spray scrubber performance.

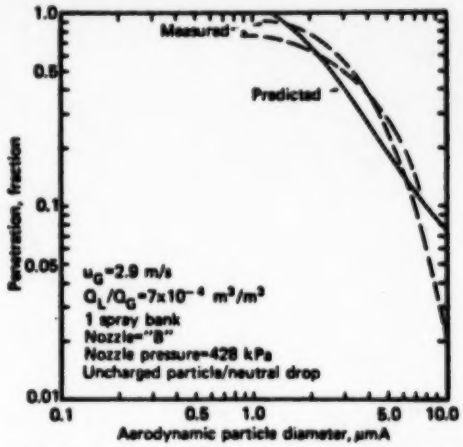

Figure 7. Predicted and measured spray scrubber penetration.

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